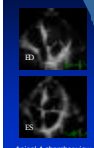
A Statistical/Registration Approach to Echocardiographic Image Analysis



Apical 4-chamber view

University of Florida

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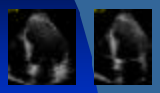
Idea People:



D. Kendal
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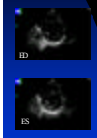
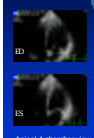


Parasternal short-axis view

- While The 20th Century was the Century of the Physical Sciences, the 21st Century Will Be the Century of the Biological and Biomedical Sciences.
- Imaging Will Play a Large Role in Many of the Breakthroughs.

Recurrent Sub-theme:

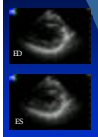


Apical 4-chamber view

Massive Image Data Overload Means Not Sufficient Time to Make Manual Measurements

(1800 Image Frames/minute)

Aspects of Imaging

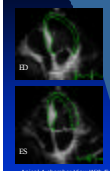


Parasternal Short-axis View

- Formation and Acquisition
- Storage and Transmission
- Analysis and Understanding
- Display

Focus of This Talk

Echocardiographic Image Analysis



Apical 4-chamber View With Expert Epi &Endo Borders

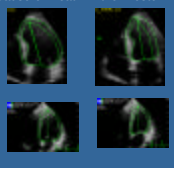
Goal: Automated Measurements and Diagnoses to Assist Physician

Examples:

1. LV Chamber Area
2. Chamber Diameter
3. Wall-Thickness
4. Area/Volume Change From ED to ES
5. Wall Motion

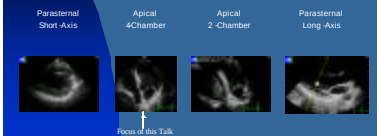
Why An Important Problem:

Answer: Heart Disease is the Number one Cause of Death in the Western World



Apical 4-chamber View With Expert Epi &Endo Borders

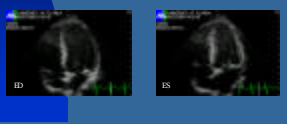
Issue: Multiple Views



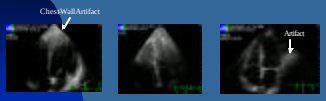
Focus of this Talk

Focus of This Talk

Images Acquired From The 4-Chamber View



Problem: Noise



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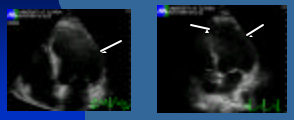
Problem: Dropout of Image Data



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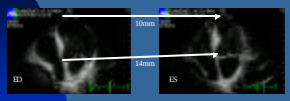
Problem: Motion During Systole



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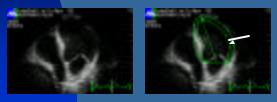
Problem

The Border May Not Occur at a High Gradient Location



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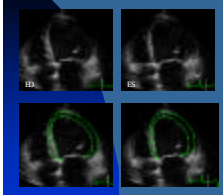
Issue: Pathology



Dilated Cardiomyopathy

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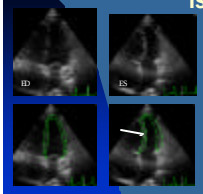
Issue: Pathology



RV Pressure/Volume Overload

(ie Weird non-convex Shape)

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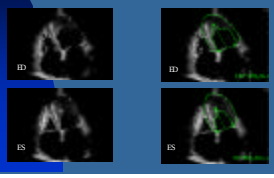
Issue: Pathology

Hypertrophy (Rare Form)



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Reason For This Research:

In Current Echocardiographic Practice Virtually All Indices of Cardiac Health Made Are Measured Either:

1-Dimensionally
or
Subjectively

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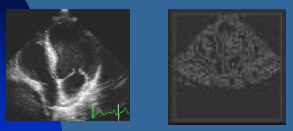
Standard "Edge Detection":



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Approach For an Automated 4-Chamber Algorithm

- 1. Create Geometric Models
- 2. Create Average Images
- 3. Formulate Model (1 frame)
- 4. Develop Numerical Techniques
- 5. Motion Tracking
- 6. Validate

Key Techniques:

- 1. Procrustes Shape Analysis
- 2. Clustering ("Black Art")
- 3. Thin-Plate Spline

Baysean Priors:

- 1. Shape
- 2. Locations of Anatomical Structures
- 2. Distances Between Landmarks
- 3. Direction & Extent of Motion
- 4. Locations of Best Image Information
- 5. Etc.

Building Geometric Models:

- 1. Beg Expert to Trace Epicardial and Endocardial Borders at ED and ES for Multiple Patients
- 2. Redigitize so Cardinalities Equal (eg 193 points)
- 3. Procrustes Shape Analysis (translate, scale, and rotate to best fit).
- 3. Separate Normals into Clusters (Ward+k-means)
- 4. Separate Abnormals into Clusters (Ward+k-means)
- 5. Compute Averages of Aligned Contours

(Clusters Formed Using "Modified Procrustes" Approach)

Remarks on Clusters

Point (=4 curves)

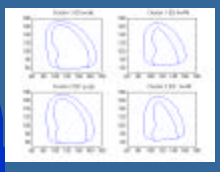
- A "Point" in a Cluster = 4 Digitized Contours (ie Epi/Endo at ED and Epi /Endo at ES)
- 167 Set of Expert Borders => 167 "Points"
- D1 = Distance Between Epi & Endo Pairs at ED After Rotation, Translation, and Scale Have Been Factored Out
- D2 = Distance Between Epi & Endo Pairs at ES After Rotation, Translation, and Scale Have Been Factored Out
- The Distance Between Two Points is D = D1 + D2

Geometric Models: Normals

Average Contours From Expert Tracings on
112 NORMAL (= 67 Patients)
Apical 4 -Chamber Images

30 Images

28 Images

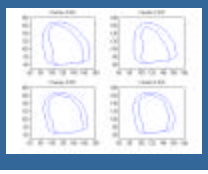


Geometric Models: Abnormals

Average Contours From Expert Tracings on
55 ABNORMAL (= 33 Patients)
Apical 4 -Chamber Images

18 Images

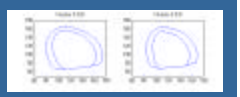
4 Images



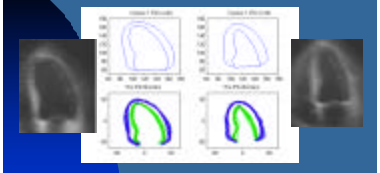
Geometric Models: Abnormals

Average Contours From Expert Tracings on
55 ABNORMAL (= 33 Patients)
Apical 4 -Chamber Images

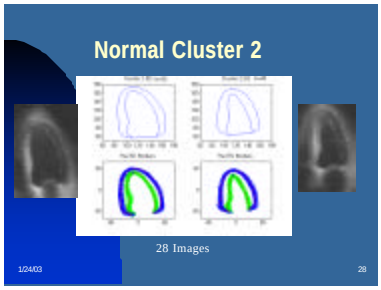
10 Images

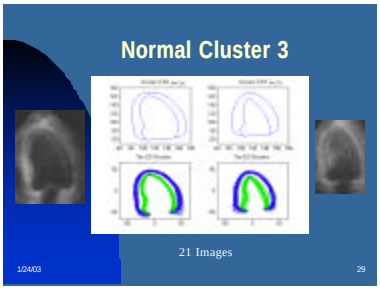


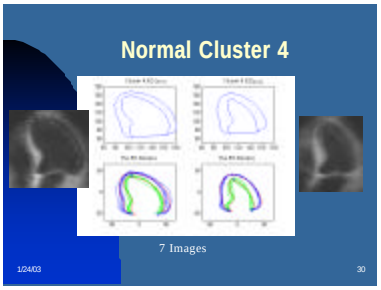
Normal Cluster 1

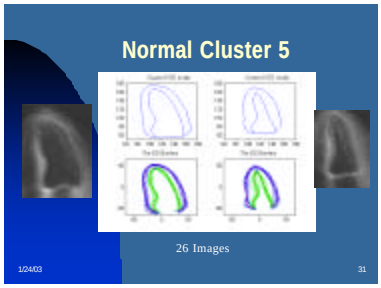


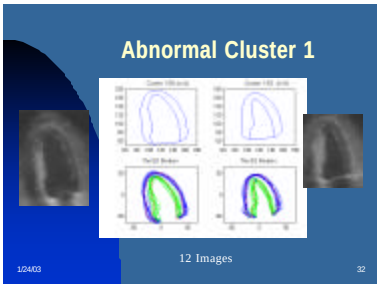
30 Images

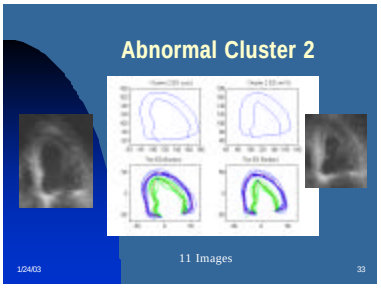

Normal Cluster 2
28 Images
1/24/03
28

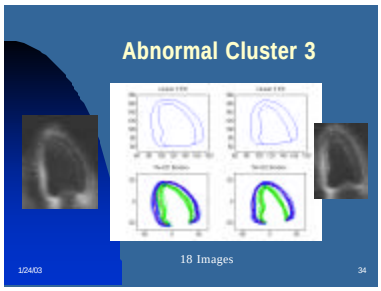

Normal Cluster 3
21 Images
1/24/03
29

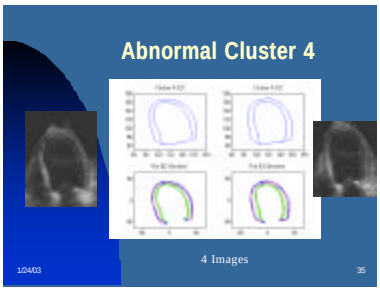

Normal Cluster 4
7 Images
1/24/03
30

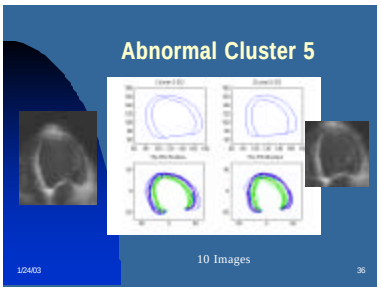

Normal Cluster 5
26 Images
1/24/03
31


Abnormal Cluster 1
12 Images
1/24/03
32


Abnormal Cluster 2
11 Images
1/24/03
33


Abnormal Cluster 3
18 Images
1/24/03
34


Abnormal Cluster 4
4 Images
1/24/03
35


Abnormal Cluster 5
10 Images
1/24/03
36

Formulate Model

Basic Idea:

Design an objective function, which matches one of the average images with a given image.

(Constrained Integral Optimization)

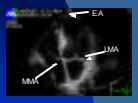
Implementation Requirement:

Speed Counts!!!!

Hybrid Implementation Strategy:

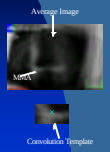
- Search for Key Landmarks First
- Combine Epi/Endo Search
- Use Edge Detection Along Septum

Search for Key Image Features:



- Medial Mitral Annulus(MMA)
- Lateral Mitral Annulus (LMA)
- Epicardial Apex (EA)

Technique For Creating Convolution Template For Locating Medial Mitral Annulus



"Clip" a Portion of the Average Image

Search Regions for Medial Mitral Annulus

A4C Mean Error(mm):
convolution template formed from average of 79 normal subjects vs expert

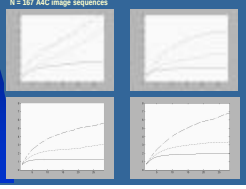
template sizes:

Upper left = 6.1 mm²at ES
Lower left = 28.3 mm²at ES

Upper right = 17.2 mm²at ES
Lower right = 17.2 mm²at Ed

EA filter = dashed line
LMVA = small dots
MMVA = solid line

N = 167 A4C image sequences

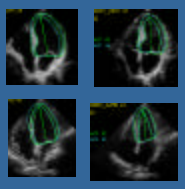


What This Means:

While the MMA Can be Located with Reasonable Accuracy, the LMA and EA Are Much More Difficult to Find

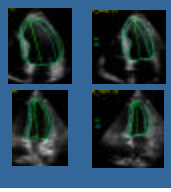
Results (Visual)

ED



ES

Results (Visual)



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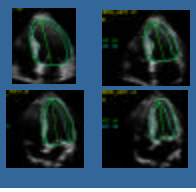
Results (Visual)



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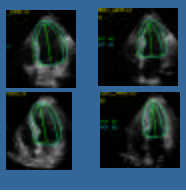
Results (Visual)



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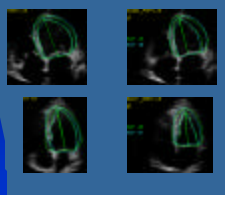
Results (Visual)



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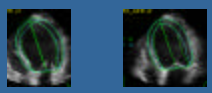
Results (Visual)



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Statistics!!!

Mark Twain Quote:

"There are lies, there are big lies, and then there is…"

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Results Chamber Areas (n=160/167)

Mean Area Diff ED (cm^2)	Mean Area Diff ES (cm^2)	Mean ACF Diff
3.25 ±3.26	3.26 ±3.43	9.68 ±10.32

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Mean Border Differences (mm) (n= 160/167)

	Epi ED	Endo ED	Epi ES	Endo ES
Mean	5.21	4.84	5.89	6.03
std	5.85	5.80	5.85	5.64

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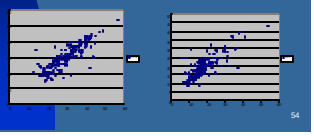
Correlations Coefficients:

Chamber Area ED = 0.83
Chamber Area ES = 0.80
Chamber Area ED/ES = 0.88



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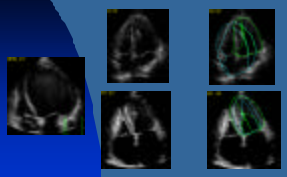
Endocardial Borders: (Circles)

ACFs(Circles):

Def: ACF = (Area_ED – Area_ES) / Area_ED

ACF(30,21) = 0.51
ACF(31,20) = 0.58
ACF(29,22) = 0.42

Failures



Challenging Next Steps

- Develop More Robust Methods to Locate the Landmarks
- Develop Better Methods to Warp the Lateral Walls to a More Accurate Fit
- 4 Views Simultaneously (For Important Stress Echo Application)